High resolution near-bed observations in winter near Cape Hatteras, North Carolina

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***Abstract*-The U.S. Geological Survey (USGS) Coastal and Marine Science Center in Woods Hole, Massachusetts, is leading an effort to understand the regional sediment dynamics along the coastline of North and South Carolina. As part of the Carolinas Coastal Change Processes Project, a geologic framework study in June of 2008 by the Woods Hole Coastal and Marine Science Center's Sea Floor Mapping Group focused on the seaward limit of Diamond Shoals and provided high resolution bathymetric data, surficial sediment characteristics, and subsurface geologic stratigraphy. These data also provided unprecedented guidance to identify deployment locations for tripods and moorings to investigate the processes that control sediment transport at Diamond Shoals. Equipment was deployed at three sites from early January, 2009 through early May, 2009: north and south of the shoals at 15 m depth, and at the tip at 24 m depth. Many strong storm systems were recorded during that time period. Mounted on the tripods were instruments to measure surface waves, pressure, current velocity, bottom turbulence, suspended-sediment profiles, and sea-floor sand-ripple bedforms. Many instruments were designed and programmed to sample in high resolution in time and space, as fast as 8 Hz hourly bursts and as small as 6 cm bin sizes in near bottom profiles. A second tripod at the north site also held a visual camera system and sonar imaging system which document seafloor bedforms. The region is known for its dynamics, and one of the tripods tipped over towards the end of the experiment. A preliminary look at the data suggests the region is characterized by high energy. Raw data from a burst recorded at the south site on Mar. 26th show instantaneous flow speed at 150 cm/s at 0.5 m above the seabed. This paper reports preliminary highlights of the observations, based on raw data, and lessons learned from a deployment of large tripod systems in such a dynamic location.**

I. INTRODUCTION

The Carolinas Coastal Change Processes Project is investigating the interactions of shoreline, near-shore, and offshore sediment transport processes driving coastal change in the states of North and South Carolina, USA. High resolution geophysical surveys have previously mapped the geologic framework and existing bathymetry, and regional numerical model development is underway. Cape Hatteras is a particularly complicated and dynamic location in the Carolina Coast where wind driven currents and waves converge from the north and south. Basic oceanographic data such as long term time series of current velocity, salinity and temperature are needed to ground truth the numerical models. Higher resolution data documenting turbulent flow at the sea-bed, the influence of wave energy, sediment re-suspension, and ripple formation are required to understand significant processes influencing sediment transport and to test numerical models.

This paper is a report on the field methods, equipment successes and failures and a preliminary look at some of the data recorded. Data shown are what has been examined so far for engineering and maintenance checks. These data have been converted from manufacturer's raw binary format to engineering units but not yet calibrated, edited and processed to USGS published standards.

Fig. 1 shows the three sites that were occupied on Diamond Shoals from January 10 to May 12, 2009; two 15 meter (m) depth locations north and south of the shoals and one 24 m depth site at the eastern tip. Four tripods and two moorings were deployed at the sites. All four tripods had upward looking Teledyne RD Instruments Acoustic Doppler Current Profilers (ADCPs) to record velocity profiles and wave spectra measurements. The north site was given the highest priority. Here, a guard buoy on a slack mooring was deployed with two tripods, one designed to measure high resolution flow near the bed with minimal obstruction in the sampling volume (Flobee) and the other designed to image the bottom (minipod). The

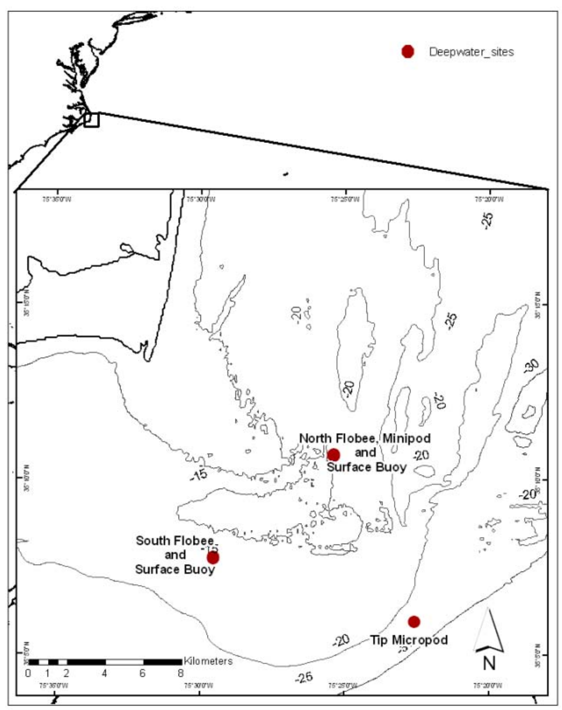

Figure 1: Overview map of Cape Hatteras, North Carolina showing the structure of Diamond Shoals and site locations.

moorings included near surface and mid-water measurements of salinity, temperature, attenuation and pressure. The south site was the second priority, also with a slack surface mooring and a Flobee tripod, but no imaging tripod. The third site at the eastern tip of the shoals was designed to measure waves and velocity profiles throughout the water column, salinity, temperature and transmission at the sea-bed. It was deployed without a guard buoy because of its deeper location and closer proximity to vessel traffic.

II. METHODS

Table I lists the instrument systems, sensors, parameters measured, water depth, and sampling schemes for each tripod. All data were stored in-situ.

A. High resolution flow tripods (Flobee)

The north and south sites were occupied by similar bottom frames designed to make high resolution near bottom measurements in both time and space. Sontek hydra systems were used on these frames to record high frequency current velocity as single point and profile measurements from acoustic Doppler velocimeters (ADVs) and pulse coherent acoustic Doppler profilers (PCADPs), and to combine these measurements with other sensors such as Paroscientific piezoelectric or Druck pressure sensors, Campbell optical backscatter, and Seatech or Wetlabs CSTAR transmission sensors. All the transmissometers were 25 cm path length and 660 nm wave length (red light) sensors. Hydra systems can record all these parameters at burst rates as high as 25 Hz, useful for turbulence measurements. An Aquatec aquascat acoustic backscatter system (ABSS) can record profiles from three different acoustic frequencies concurrently at similar sampling rates, and was included on these tripods. In previous deployments, the USGS has found that the 5 MHz transmit frequency of the Sontek ADV oceanprobe can create interference in the ABSS data if a 5 MHz transducer is used on the ABSS, but for this deployment, only one 4 MHz transducer was available. 1 and 2.5 MHz transducers were deployed at both sites, a 4 MHz probe at the north site and a 5 MHz probe at the south site.

Hydra and ABSS systems share a synchronization feature that is very useful for this type of experiment where high frequency measurements are used to compute turbulent statistics. Unfortunately, it was not possible to synchronize all four high resolution systems (two ADVs, PCADP, ABSS) together as no single system was able to drive the electrical load of three of the others. In addition, the ADV synchronization pulse was very short, and bench tests proved that an ADV could only be synchronized with another ADV. To capitalize on the synchronization as much as possible, the two ADV systems were synchronized to each other, and the ABSS was synchronized to the PCADP on the north tripod. The PCADP on the south tripod did not have the synchronization feature.

Fig. 2 shows the Flobee frame deployed at the south site. This tripod, 3.8 m high and 2.9 m wide, provided a platform to raise the bulk of the pressure cases, release systems and support equipment 2 m from the sea-bed in order to reduce hydrodynamic contamination. Stability is achieved with 200 to 300 lb weights on each leg. In order to achieve 4 months of high resolution recorded data, 5 of the 10 pressure cases on each frame contained alkaline batteries. The large high drag items such as pressure cases and the pop-up release system are mounted at the top of the frame. Underneath, within the protective framework of the legs, are most of the sensors. Visible, from left to right, are two optical backscatter sensors (OBS) on the left tripod leg, a Seabird microcat near the top of the leg, the probe for a Sontek PCADP below the microcat, two Sontek ADV probes to the right of the PCADP, a Wetlabs transmissometer above the ADV probes and the transducers from an ABSS near the leg in the foreground. Not visible at the top of the tripod were an upward looking ADCP, Seabird seacat and Wetlabs CSTAR transmissometer.

Figure 2: Flow tripod intended for the south site being prepared for deployment aboard the R/V Connecticut by Brandy Armstrong, John Warner, Jonathan Borden and Neil Ganju. The annotation for the transmissometer has been abbreviated as “trans.”

B. Minipod

At the north site, the second tripod contained equipment that would have contaminated the measurement volume of the larger tripod. On this smaller tripod were a time series camera and a sonar imaging system used to record changes in sea-bed morphology.

The camera system consists of a Konica Minolta A2 commercial camera in a pressure case with a transparent end cap, triggered by external circuitry to take images every two hours. A strobe light was triggered to illuminate the bottom. The sonar system consists of a Persistor data logger which controls two sonar heads The data logger was designed and built by the Woods Hole Oceanographic Institution [1], and collected sonar data every 6 hours. The sonar heads are an Imagenex rotating fan beam and a pencil beam. The pencil beam data will be used to calculate the height of the bed forms imaged by the fan beam sonar, continuing work by Voulgaris and Morin [2]. The fan beam collected 360 degrees of data in 0.15 degree steps and the pencil beam was rotated by an azimuth drive in a 360 degree circle, collecting one sweep every 3 degrees. Sediment volume concentration at different size classes was measured by a Sequoia laser in-situ scattering and transmissometry instrument (LISST). Also included were a seacat and Seatech transmissometer and upward looking ADCP.

C. Micropod

Basic measurements were needed at the eastern tip of Diamond Shoals to measure the boundary conditions in support of the north and south measurements. A 1 m high frame was deployed with an upward looking ADCP, seacat and Seatech transmissometer.

D. Surface moorings

Slack surface moorings were deployed as guard buoys near the tripods at the north and south sites. Design of moorings intended to guard tripod locations is a balance between the size of the mooring's watch circle and compliance needed for surface motion. These were slack moorings with Mooring Systems G2000 buoys, 2100# anchors and 20 m of ¾" chain and instrumentation load cages. Instrumentation included ARGOS (Seimac CML) and Iridium (Xeos melo) satellite beacons on the buoys to track position, seacats, Seabird SBE49 pressure loggers and Seatech transmissometers at 5 m depth at both sites, and a microcat on the north buoy. The deployment depth was 15 m and the moorings were expected to move during the deployment.

E. Bio-fouling prevention

Biological growth on sensors in coastal environments can contaminate the measured signal, even during winter months. Steps were taken to control the growth of biological fouling on the optical and acoustic sensors to maximize the amount of usable data. Acoustic transducers such as on the ADCP, PCADP, ADV and ABSS were coated with a light layer of zinc oxide cream, which is more typically used to prevent diaper rash in infants.

Optical sensors, such as the OBS, transmissometers, LISST and camera, were protected by a combination of methods. The Wetlabs square bodied transmissometers were wrapped in copper tape to prevent fouling on the body of the sensor, while the Seatech transmissometers had to be painted with tributyltin bottom paint. The optical lenses for both transmissometers were fitted with tributyltin leaching rings [3] on the north mooring and the Flobee tripods. This experiment also tested a Zebratech timed wiper mechanism which was fitted to an OBS on the north tripod. It passed a brush across the face of the sensor every 3 hours. The rest of the OBS sensors were coated with clear tributyltin spray paint. Copper tape was used around the face of the camera's window. The LISST had no protection from fouling.

To prevent a bias in the salinity readings from sediment accumulation in the conductivity cells, pumps were added to the seacat data loggers on the tops of the Flobee tripods. Older microcats and seacats without pump capability were used on the moorings and smaller tripods. Data from these conductivity cells will be examined for a consistent freshening trend, a signal typical of cell contamination by sediment, seen in previous USGS deployments.

F. Recovery Methods

Due to the dynamic nature of the Diamond Shoals site, it was possible that one or more of the tripods might tip over, particularly the very tall Flobee frames which concentrated the pressure cases into a large drag body at the top. The 300 lb weights on each tripod foot at the north site and 200 lb legs on each tripod foot at the south site lowered the center of gravity to prevent tipping. The north site was expected to experience stronger wave and currents. The south site was expected to be more protected from northeast storms by the structure of the shoals, and thus any borrowed equipment was placed at this site.

Each of the tripods was equipped with a pop-up buoy system designed to bring a lifting line to the surface for fast, convenient recovery. The ORE Offshore 8242XS and Coastal Acoustic Release Transponder (CART) releases on all the tripods include the ability to report orientation, vertical or horizontal, as well as the ability to transpond with an acoustic ping. Each tripod was fitted with additional Benthos 25 to 32 kHz transponders that are searchable by a diver hand-held or pole mounted ranging unit. Old Edgetech AMTR200 releases were added as backup transponders and not attached to the lifting line. It was hoped that one or more of these methods would enable the tripods to be located if they became buried.

A remotely operated vehicle (ROV) was brought on the recovery cruise and proved necessary to recover all but one of the tripods. At the north site, the larger Flobee tripod was found to be horizontal by interrogating the acoustic release. The last data recorded while the tripod was vertical were 21:51:16, Apr. 16th, 2009. At the south site, the Flobee tripod was found upright on recovery and the pop-up recovery system succeeded in bringing the lifting line to the surface. However, the spectra line parted during recovery due to

TABLE I
LIST OF DEPLOYED INSTRUMENTATION

Instrument	Sensor	Measurements	Sampling
North at 14.7 m Depth and South at 14.0 m Depth Flobee Tripods			
Sontek hydra	Acoustic Doppler velocimeter (ADV), thermistor	3D flow velocity, temperature	8 Hz for 17.5 min hourly
	Pulse coherent acoustic Doppler profiler (PCADP), thermistor	Profiles of 3D flow velocity, temperature	1 Hz for 17.5 min hourly, 6.3 cm bins
	Pressure, Paroscientific and Druck piezoelectric	Pressure	1 or 8 Hz for 17.5 min hourly
	Transmissometer, 25 cm path length	Attenuation	1 or 8 Hz for 17.5 min hourly
	Optical backscatter sensor	Optical backscatter	1 or 8 Hz for 17.5 min hourly
Aquatec aquascat ABSS	1, 2.5 and 4 (north) or 5 (south) MHz transducers	Acoustic backscatter profiles	1 Hz for 30 min hourly, 5 cm bins
TRDI ADCP	Acoustic Doppler Current Profiler with strain gauge & thermistor	Profiles of 3D flow velocity, pressure, temperature	5 min, 50 cm bins
	Acoustic wave array	Directional wave spectra and statistics	2 Hz for 17 min hourly
Seabird microcat	Fast thermistor, conductivity	Temperature, salinity	5 min
Seabird seacat	Fast thermistor, pumped conductivity	Temperature, salinity	5 min
North 15.0 m Depth and South 13.8 m Depth Surface Moorings			
Seabird microcat	Fast thermistor, conductivity	Temperature, salinity	5 min
Seabird seacat	Fast thermistor, conductivity	Temperature, salinity	5 min
	Transmissometer, 25 cm path length	Attenuation	5 min
Seabird SBE39	strain gauge sensor	Pressure	5 min
North 14.78 m Depth Minipod Tripod			
Sequoia LISST	Laser scattering	Volume concentration, 32 size classes	5 min
	Laser transmission	Attenuation	5 min
	Thermistor	Temperature	5 min
	Strain gauge	Pressure	5 min
TRDI ADCP	Acoustic Doppler Current Profiler with strain gauge sensor & thermistor	Profiles of 3D flow velocity, pressure, temperature	5 min, 50 cm bins
	Acoustic wave array	Directional wave spectra and statistics	2 Hz for 17 min hourly
Seabird seacat	Fast thermistor, conductivity	Temperature, salinity	5 min
	Transmissometer, 25 cm path length	Attenuation	5 min
Imagenex sonar	Rotating fan beam	Acoustic backscatter image of bottom	6 hour
	Pencil beam on rotating azimuth drive	Range to boundary	6 hour
Camera system	Konica Minolta A2 digital camera	Bottom images	2 hour
East Tip 23.7 m depth Micropod Tripod			
TRDI ADCP	Acoustic Doppler Current Profiler with strain gauge & thermistor	Profiles of 3D flow velocity, pressure, temperature	5 min, 50 cm bins
	Acoustic wave array	Directional wave spectra and statistics	2 Hz for 17 min hourly
Seabird seacat	Fast thermistor, conductivity	Temperature, salinity	5 min
	Transmissometer, 25 cm path length	Attenuation	5 min

shock loading from heavy seas. The smaller north minipod also remained upright, but the Samson lift line was sucked out of the rope canister and was found to be wrapped around one of the legs. The line can be seen in the bottom images as early as Jan. 23rd and throughout the rest of the sonar record. The east Tip tripod remained upright and was recovered normally.

G. Sensor alignment and tracking

Magnetic compasses in the ADCP, ADV and PCADP are used to measure heading on the sea-bed. Often, measurement errors from these sensors can include magnetic fields on the tripod frame, poor calibrations or failures. To troubleshoot heading inaccuracies and compass failures, the USGS has developed a method of aligning sensors and measuring the difference in rotation between sensors which contain compasses or require a heading alignment in post processing. Knowing the relative alignment of sensors allows data processors to compensate for failed compasses and increase the confidence in directional measurements (Fig. 3).

Common tools from the construction industry are used to make a chalk map on the ground below the tripod. The map is then recorded as a series of Cartesian coordinates. A laser plum bob set below each sensor allows a mark to be made locating the center of each measurement volume. Jigs which hold a laser chalk line projector were tailor made for the ADCP, the PCADP and the ADV. The laser line is used to define the orientation of each sensor, using the zero point of the sensor's compass as the reference. Each leg of the tripod was marked with a different color. With all this recorded information, a three dimensional map can be made of the tripod which includes the location and orientation of each sensor with respect to the sea-bed.

Color coding, along with system serial numbers, provided more positive identification of sensors, and prevented confusion where multiple identical sensors and systems are attached to the same tripod frame. Color was used to identify sensor location and orientation in photographs of the equipment taken before and after the deployment. Each of the hydra systems was assigned a color, and each tripod leg was spray painted with a distinct color. These colors are used to identify the sensor and tripod legs in Fig. 5-7.

Figure 3: Kurt Rosenberger recording the relative position and rotation of an ADV on a tripod during the Palos Verdes Shelf experiment. The location points and directional chalk lines were made with the help of a laser chalk line and a laser plum bob. These methods were also used for the Cape Hatteras experiment.

III. Results And Data

The data loggers and sensors deployed worked throughout the experiment with a few exceptions. One of the ADVs at the north site failed to record data properly. Preliminary evidence suggests the logger overwrote its memory. The sonar system stopped logging in mid-March, likely due to exhausted batteries. One OBS had a leak at the bulkhead connector, and another had a broken connector on recovery, but both appeared to work throughout most of the deployment. An ADV probe was lost when the ROV hooked into one of the guy wires, rather than one of the tripod's legs.

Both moorings remained intact and on station within 50 m of the original deployment sites for the duration of the deployment. Two small shifts in position of the buoy at the north site were recorded by the satellite beacon. On Jan. 20-21st, there was a 15 m shift in position to the south, from Mar. 28 to Apr. 14th the buoy moved back north, gradually, by about 5 m, and finally from Apr. 16-17th, there was a second abrupt movement south by about 10 m. This later movement coincides with the time when the Flobee tripod at the north site tipped over.

Fouling was the greatest cause of loss of data. The OBS sensor data quality was good until April, after which data quality was affected by biological growth obscuring the sensor windows. The OBS with the mechanical wiper returned good data throughout the deployment, and the sensor's window was found to be clear of any biological growth on recovery. Good data for the entire deployment were recovered for two of the three transmissometers on the Flobee tripods. These sensors were fitted with tributyltin leaching rings. Transmissometers with the leaching rings were found to have only a few 1 mm barnacles on the lenses, where untreated sensors were completely blocked by barnacle encrustation. Data from these barnacle covered transmissometers have not been processed, so their endurance is not yet known. The LISST was not fitted with any bio-fouling prevention devices. LISST attenuation data indicate that fouling blocked the laser windows as early as Feb. 4th, 2009, and similar results are expected for the unprotected transmissometers. The camera fared much better in spite of only having copper tape around the periphery of the camera window. Bottom ripples are clearly visible in late April in spite of bio-fouling. Fig. 4 is an example of the clarity of the camera image during heavy bio-fouling. A loggerhead sea turtle was in the camera's field of view on Apr. 19th.

All four ADCPs recorded a complete record of mean current and wave data, concurrently in both burst (2 Hz for 17 min every hour) and interval mode (average every 5 min) without any data gaps or interpolation. The two ADCPs at the north site, on the Flobee and minipod frames, agree well. This is based on preliminary processing and not quality controlled data. Flow, directional wave spectra, sea surface height spectra and other derived parameters will be available once all processing is finished and are not discussed in this paper. The 1200 kHz ADCP at the east site was deployed at 24 m, deeper than its maximum acoustic range, and therefore the profiles from this ADCP never reached the surface. This will have some consequence for the interpretation of the wave spectra. This ADCP also experienced a number of automatic restarts; however this does not seem to have affected the quality of the data.

The sonar system worked until mid-March, collecting fan beam images such as the example in Fig. 5 and pencil beam sweeps, such as the example in Fig. 6. Annotations on the image in Fig. 5 show the extent of the tripod structure in the center of the sonar's near field and the location of the pencil beam measurements. Shadows from the tripod's legs and upright members are visible. Also visible at the upper right is the lifting line which came free from the rope canister. The target placed on one of the tripod legs (the green leg) to differentiate it from the others produced the darkest shadow. The sonar heads and ADCP were subjected to the same alignment procedure used on the Flobee tripods. From this information, the larger shadow in the image in Fig. 5 confirms the orientation of the tripod on the bottom, and the resulting image can always be oriented to north up using the ADCP heading data. In Fig. 6, the dips seen in the sea-bed increase over the course of the deployment and may indicate scouring around the tripod feet.

A good data record was recovered by most of the hydra systems. Fig. 7 shows eight time series plots of data over the entire deployment collected by the hydra systems on the south tripod. There were two ADVs (green and orange) and a PCADP (brown system). Data are hourly averages of bursts collected at 8 Hz for 17 min, shown before any editing or filtering was performed to clean up the data. The brown PCADP data stop on Apr. 23rd when the data logger's memory was filled. Plot 1 shows speed from the two ADVs at 52 centimeters above bottom (cmab) and one cell of the PCADP at 51 cmab. The difference between the burst averaged speed from the PCADP and the ADVs increases with an increase in speed; however the difference between the two ADV burst averaged speed measurements does not show this trend. Plot 2 shows ADV and PCADP flow direction, usually from the east or west. Peaks in flow speed appear to coincide with easterly flow directions, as indicated by the blue dashed line B on Mar. 30th. Plots 3 and 4 show the difference between the initial value of the ADV and PCADP pitch and roll and each subsequent hourly average of pitch and roll. The pitch and roll data compare well until Mar. 28th, and then diverge significantly. This is due to a large number of spikes in the raw burst data, which cause a significant bias in the burst averages and will have to be edited or filtered.

Plots 5 and 6 in Fig. 7 show data from two of the three pressure sensors, a Paroscientific at 198 cmab attached to the orange ADV and a Paroscientific at 196 cmab attached to the green ADV. A Druck pressure sensor was in the brown PCADP probe at 113 cmab, but the data have not yet been processed. Peaks in pressure standard deviation in plot 5 coincide with a westerly flow direction, as indicated by the blue dashed line A on Mar. 26th. In plot 6, the green and orange depth measurements differ by only 2 cm during the first 1000 hours of the deployment. At certain times, such as Feb. 21st and Mar. 5th, and then more frequently later in the deployment, the pressure record of the orange ADV diverges from the green ADV. At these times, the burst pressure data are noisy and degraded, possibly due to a bad cable connection, causing a bias in the hourly average and will have to be edited or filtered.

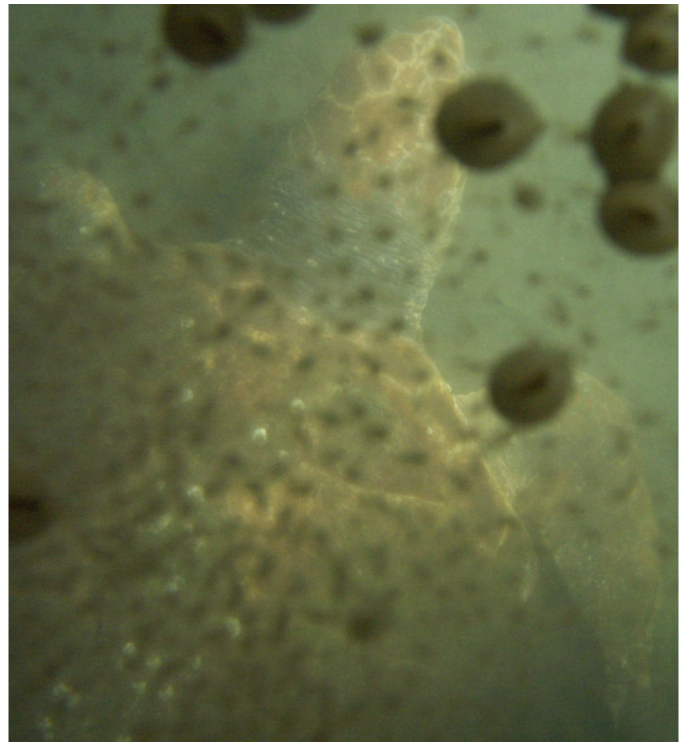

Figure 4: The time series camera captures a loggerhead sea turtle sheltering under the tripod at 18:55 on Apr. 19, 2009. The animal is clearly visible in spite of numerous barnacles and other growth on the camera window.

Plots 7 and 8 in Fig. 7 show measurements made with optical sensors. Two OBS sensors were attached to the green and orange ADV systems, at 65 and 133 cmab respectively. The OBS records degrade after Mar. 28th, probably due to a corroded connector in the case of the green OBS and bio-fouling in the case of the orange OBS. Two transmissometers were attached to the green and orange ADV systems at 259 cmab and 155 cmab respectively. The orange transmissometer data have long periods of time at the beginning of the deployment where the signal drops to near zero, but this problem goes away at the end of the deployment. No problems were found with the cables on recovery, so these dropouts might be due to an animal blocking the sensor volume or an intermittent cable or electronic problem. Noise in the hydra sensor records is sometimes a result of low battery voltage, and in this data set the noise increases towards the end of the deployment. These data will be filtered or edited during the next processing steps.

The plots in Fig. 7 and 8 suggest the magnitude of the typical storm generated wave orbital velocity response to the many storms which impact Cape Hatteras. Fig. 8 is a plot of data from one burst on Mar. 26th, 2009 at the time marked by the blue dashed line A in Fig. 7. Data are in engineering units, unedited and unfiltered, and calibrations have not been applied. In Fig. 8, the data from the Orange ADV were delayed by 18 seconds to align them with the Green ADV, based on the burst pressure data. The Paroscientific pressure sensors were 93 and 47 cm from the Green and Orange ADV probes, respectively, and less than 200 cm from each other. These two systems should have been synchronized such that the green ADV would trigger the orange ADV to start a burst at the same time. The need to shift the burst data by this many seconds suggests that synchronization was not successful. Dissimilarity between the speed and direction for the green and orange ADV data in Fig. 8 might be explained by either turbulent eddies from the tripod frame or limitations of the instrumentation.

Acoustic backscatter profile (ABSS) data were returned for all three frequencies on both instruments (north and south Flobee tripods). As expected, the southern ABSS 5 MHz data show evidence of 5 MHz interference from the ADV; however the signal to noise ratio of the backscatter from sediment versus the interference from the ADV probe appears to be large enough to recover the data. Fig. 9 shows a typical ABSS record for one 30 min. burst on Mar. 3rd, 2009. This was a time period of low re-suspension, so the near field response is very clear at the top of the image. At the bottom of the image, the strong return of the bottom is evident with small re-suspension events a few centimeters above the sea-bed.

Cape Hatteras is a very popular fishing area. This is supported by the number of fish seen when using the ROV and its onboard sonar to recover the tripods, and the presence of the sea turtle and other fish in a number of the bottom images. Fish, appearing as targets on the ROV sonar, are what enabled USGS technicians to locate the tripods with the ROV in very poor visibility. Fish targets are also frequently visible in the acoustic backscatter records when there is little sediment re-suspension, and an example is shown in Fig. 9.

Changes in tilt in the ADV, PCADP and ADCP suggest that the north and south Flobee tripods and the minipod at the north site all shifted several times during the deployment (aside from the event that tipped over the north tripod). A 20 to 30 cm change in the distance from the ABSS transducers to the sea-bed has also been observed in both the north and south sites. The ABSS range to boundary and sonar fan beam image data suggest sand waves migrating under the tripod. Preliminary analysis of the sonar data also shows a significant slope to the sea-bed under the minipod at the north site.

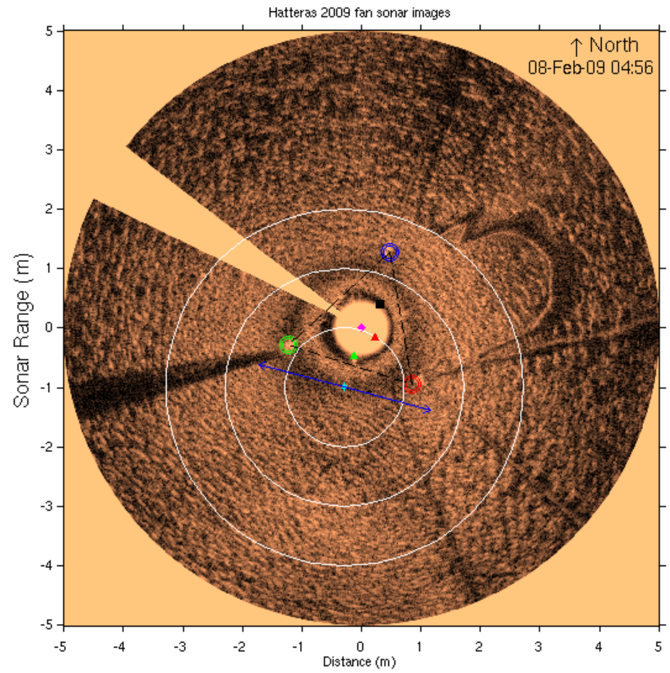

Figure 5: Example image from the fan beam sonar showing the detail of bottom ripples. The fan beam sonar head is positioned in the center of the image. Also shown are the tripod framework (dashed line), legs (green, blue and red circles), the location of the pencil beam sonar head (green dot in white range circles), and the orientation of the pencil beam's field of view (solid blue line). The pencil beam image is shown in Fig. 6.

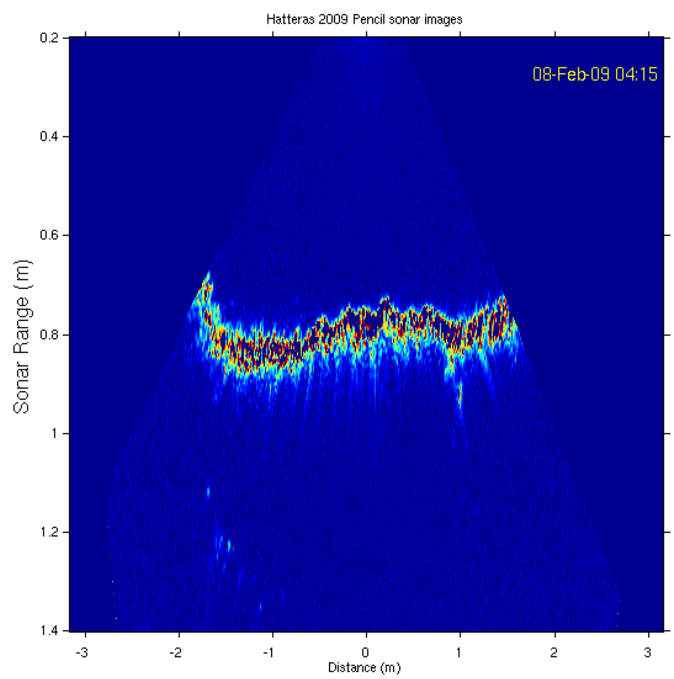

Figure 6: Pencil beam sonar image recorded after the fan beam image in Fig. 5. The image is the bottom reflection along the solid blue line in Fig. 5. The shape and level of the bottom changed over the deployment.

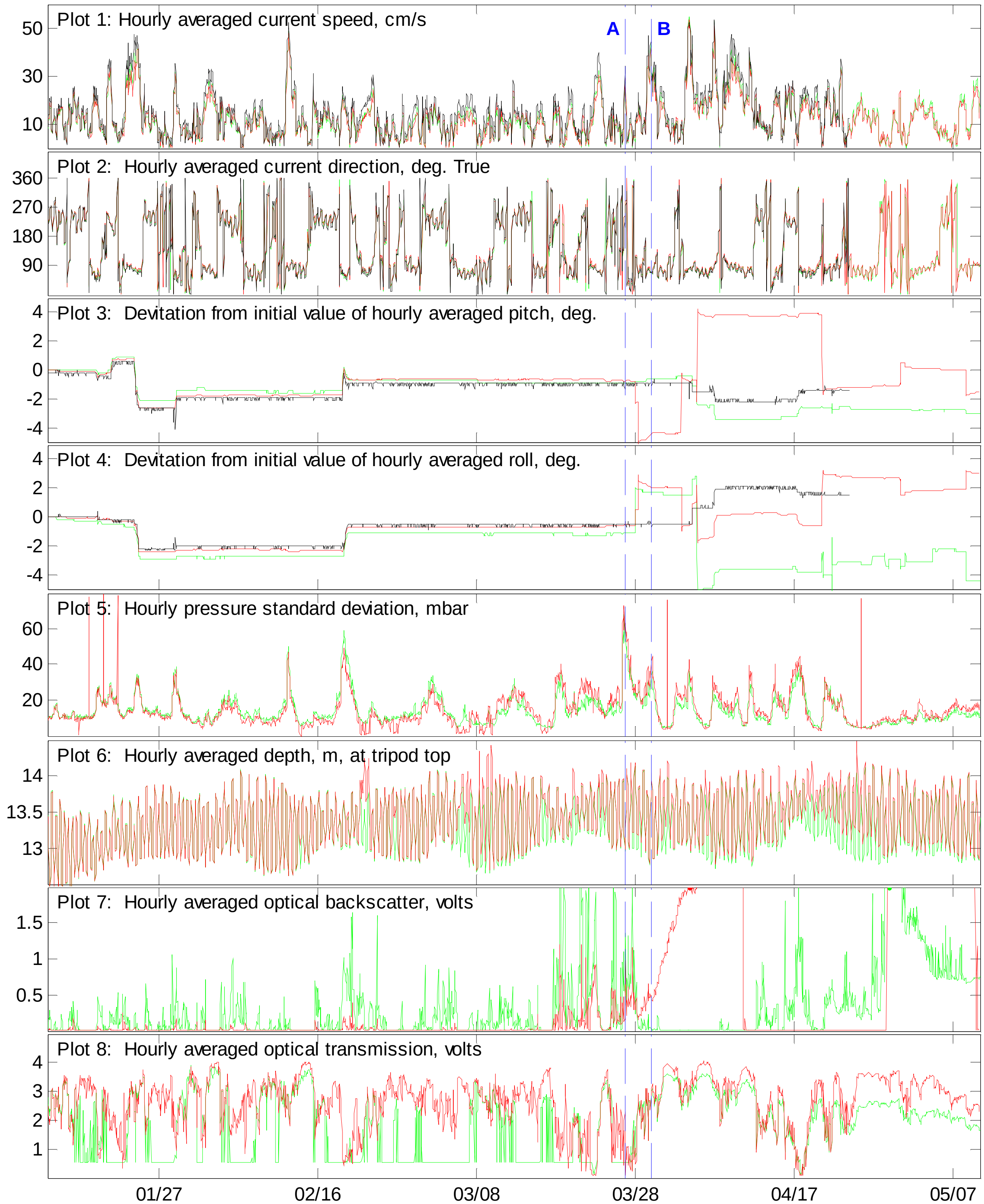

Figure 7: Plot of hourly averaged time series data over the entire deployment from the south Flobee tripod. Current speed and direction data are shown for the green ADV system at 52 cmab (green solid line), the orange ADV system at 52 cmab (red solid line) and one cell in the profile from the brown PCADP system at 51 cmab (black solid line). The deviation of the pitch and roll from the initially deployed value are also shown. Pressure, optical backscatter (OBS) and optical transmission are shown for the green (green solid line) and orange (red solid line) systems. The Brown PCADP system did not have the capability to record external sensors, and it filled its memory earlier than the ADV systems. Dashed lines A and B correspond to the dates Mar. 26, 2009 18:51:17 and Mar. 30, 2009 03:51:16 respectively.

Figure 8: Speed, direction and depth from the green (green solid line) and orange (red solid line) ADVs at the south site during a strong storm. Data are shown for one 17 minute burst, sampled at 8 Hz on Mar. 26, 2009 at the time indicated by dashed line A in Fig. 7. ADV probes were mounted 67 cm apart and the pressure sensors were 100 cm apart.

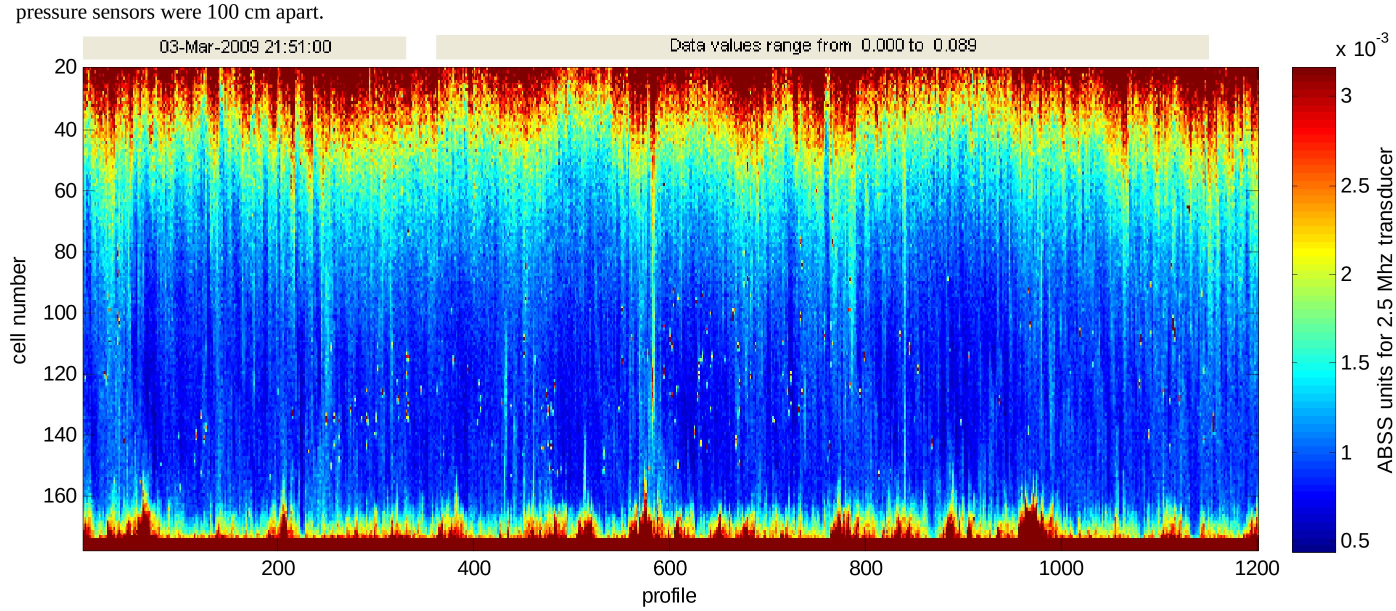

Figure 9: Plot of profiles from one burst of ABSS data for the 2.5 MHz transducer, recorded at 1 Hz for 30 min. on Mar. 3rd, 2009 21:51. Data are in raw units and indicate relative strength of the acoustic return. This was a time period of low re-suspension. Visible in the water column are acoustically reflective targets, probably fish.

The data suggest that a significant event occurred on Apr. 17th. The plot of transmissometer voltage reaches a nadir at this time, coincidently with a peak in OBS voltage output, a peak in pressure standard deviation and a 0.5 m separation between the two ADV pressure records. The change in pitch and roll also shifts at this time. This is the same time that the north tripod was tipped over and the north buoy made one of its movements to the south. ADV data from the north tripod (not shown) on Apr. 16th reach 150 cm/s magnitudes of the current velocity and 4 m range of the sea surface height over a period of 300 seconds. Preliminary examination of the data from the north site indicates that this was the most powerful storm recorded during the deployment.

IV. CONCLUSIONS

Given the risk involved, this deployment of equipment for four winter months has been a great success. In spite of turbulent forces clearly strong enough to shift the largest of the tripod frames and move the north mooring, the equipment remained stable enough to record a landmark data set. Antifouling techniques prevented blockage of optics long enough to provide enough optical backscatter and transmission data to compliment acoustic methods. The LISST data record, while severely shortened by bio-fouling, might be used to ground truth the ABSS. Enough data have been collected to serve as an excellent ground truth to the regional sediment transport models under development by the USGS Coastal and Marine Program.

Complications for this data set include the usual long term deployment issues, such as decisions about when bio-fouling compromises data quality beyond usefulness, accounting for relative clock drift and shifts in tripod position. Spikes and noise in the ADV and PCADP burst data will need editing and filtering before more meaningful statistics can be calculated. More interesting problems will include how to interpret directional wave information derived from ADCP measurements made 5 m below the surface; matching bottom camera images to sonar derived ripple direction and size in an automated way; and aligning high frequency measurements in time, perhaps using pressure measurements or acoustic interference patterns. Finally, there is a chance to partially recover the data from the ADV that overwrote its memory using forensic methods.

Low power, long endurance instrumentation and bio-fouling prevention methods continue to be the highest priority for USGS sediment transport studies. Without such equipment, such a long deployment in such a difficult location would not have been possible. It was not clear, at the beginning of the experiment, that Cape Hatteras weather would allow access to deploy the equipment. The endurance of the instrumentation was even more critical in this deployment since weather, and as often, funding logistics and ship availability, stretched the length of deployment to four months. Thanks to lower power design, data were collected during the entire deployment and therefore the return on the expense and effort was maximized for this experiment.

Future plans for this work include testing two techniques developed by the University of South Carolina to automate analysis of sonar fan beam data [3] and to extract median grain size from ABSS data where three frequencies of data were successfully recorded. A shutter mechanism is planned that can be used to prevent fouling on the LISST and the camera. An adaptation of the wiper mechanism for the OBS is being tested on a transmissometer. This may remove the need to use tributyltin in the future. Finally, planning is underway for a follow up study to record complimentary data in the near shore environment of Cape Hatteras in the spring of 2010.

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DISCLAIMER

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